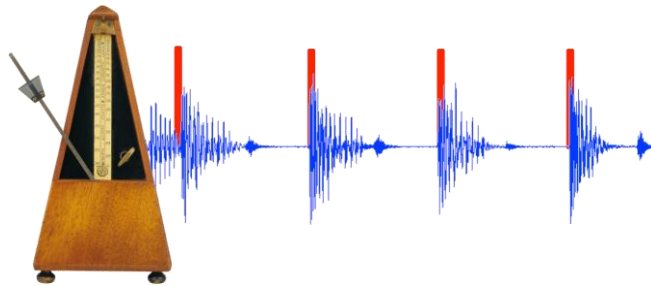


IEEE SIGNAL PROCESSING CUP 2017: REAL-TIME BEAT TRACKING CHALLENGE



This competition is sponsored by the IEEE Signal Processing Society.

Acknowledgements: Daniel Levitin, Steven Hainsworth, Dan Ellis, Mark Plumbley, Simon Dixon, Meinard Müller for contributions and permission to use text.



1. The Beat-Tracking Challenge

The beat is a salient periodicity in a music signal. It provides a fundamental unit of time and foundation for the temporal structure of the music. As Meinard Müller says (Fundamentals of Music Processing, Springer, 2015), “It is the beat that drives music forward and provides the temporal framework of a piece of music. Intuitively, the beat corresponds to the pulse a human taps along when listening to music.” The significance of beat tracking is that it underlies music information retrieval research and provides for beat synchronous analysis of music. It has applications in segmentation of audio, interactive musical accompaniment, cover-song detection, music similarity, chord estimation, and music transcription. It is a fundamental signal processing task of interest to any company providing information services related to music (adapted from Degara *et al.*, Reliability-informed beat tracking of musical signals, IEEE Trans. on Audio, Speech, and Language Processing, **20**:1, 290-301, 2011).

The goal of this challenge is to implement a real-time beat tracker on an embedded platform and to demonstrate the performance with a creative output such as, but not limited to, drumming, dancing, or flickering lights. It is challenging to perform beat tracking in real time because the complete signal

is not available. It is also challenging because there can be a wide variety of musical input and the system needs to perform well on all of them.

2. Competition Organization

The competition consists of two stages, open competition that any eligible team can participate, and the final competition that is only open to finalists. The open competition tasks must be completed by **December 21, 2016** and the three best teams are selected and announced by **January 10, 2017**. The final competition will be completed by the three finalist teams and will be judged at ICASSP 2017 which will be held **March 5-9, 2017**.

Overview

Open Competition – Part 1: In Part 1, a database of 50 musical excerpts is provided. Half of the database has human annotated beat times provided. For the other half, the annotated beat times are kept hidden. The participation requirement for Part 1 is to submit three 30 s musical excerpts with human annotated beat times. The objective is to engage participants by getting them doing their own human annotated beat times. Participants get to select one musical excerpt as a Challenge Piece for the competition. The annotated beat times for the Challenge Piece are not revealed.

Open Competition – Part 2: In Part 2, participants are provided with all of the submitted 30 s musical excerpts and their annotated beat times (excluding the annotation for the Challenge Pieces). Participants then have to develop a real-time beat tracker on any embedded device such as the Raspberry Pi. The performance of the beat tracker will be judged based on beat-tracking performance and the creativity of the application.

Final Competition: After the three best teams from the open-competition stage are selected, a selection of database excerpts and the Challenge Pieces selected by the three best teams will form the final test material. Teams are asked to refine their algorithms based on the final test material and report the beat-tracking test results for the final test material. The three teams will be invited to ICASSP 2017 to present their real-time embedded beat-tracking application.

Details

Open Competition – Part 1

In Part 1 of the challenge, participants will be provided with a database of 50 musical excerpts spanning a range of styles and difficulties. For 25 of the musical excerpts, human annotated beat times will be provided and for the other 25 musical excerpts, the annotated beat times will not be revealed. Participants will use the database to develop their real-time beat tracking

algorithms. At the end of Part 1, participants will be asked to submit three musical excerpts 30 seconds in length and to provide human annotated beat times for each musical excerpt. Participants are encouraged to select musical excerpts that should be challenging for competitors, but that their own beat-tracking algorithm performs well on. The submitted human annotated beat times will be validated and scored by the Competition Organisers. Participants should also nominate one of their musical excerpts as a Challenge Piece. After validation and scoring, all of the participant submitted musical excerpts will be made available to participants. As well, all of the validated annotated beat times, excluding those for the Challenge Pieces, will be made available.

Provided: Database of 50 musical excerpts: 25 with annotated beat times and 25 not annotated.

Submitted: Three 30 s musical excerpts with human annotated beat times. One of the musical excerpts should be nominated as a Challenge Piece.

Open Competition – Part 2

For Part 2 of the challenge, participants should improve their algorithms based on the participant submitted musical excerpts and beat time annotations. Participants should also implement their real-time algorithm on any embedded device such as Raspberry Pi, Arduino, etc. At the end of Phase Two, participants will be asked to submit: (1) a software version of their real-time beat-tracking algorithm for evaluation with instructions on how to run it; (2) the beat time output for their real-time algorithm for both the database and the participant submitted musical excerpts; (3) a video demonstrating the real-time operation and creative output of their embedded device for an easy musical excerpt and a hard musical excerpt ('hard' meaning a musical excerpt which in the participants' opinion is one of the more difficult excerpts for which their real-time implementation works); (4) a report in the form of an IEEE conference paper describing the technical details of the real-time beat tracking implementation.

Provided: All of the 30 s musical excerpts submitted by participants and annotated beat-tracking for all but the Challenge Pieces.

Submitted: **1.** Software with instructions on how to run it. **2.** Beat time output for the real-time embedded device for both the database and participant submitted musical excerpts. **3.** Video demonstrating real-time operation for both a hard piece and easy piece. **4.** A report in the form of an IEEE conference paper describing the technical details of the real-time beat tracking implementation.

Final Competition

Three best teams will be selected by the judging committee based on the accuracy of the beat tracking and the creativity of the real-time beat tracking

application. The three teams will be provided with final test material comprised of a selection of database excerpts and the Challenge Pieces selected by the three best teams. The three teams are asked to refine their algorithms based on the final test material and report the beat-tracking test results for the final test material. The three teams will be invited to ICASSP 2017 to present their real-time embedded beat-tracking application. Teams will present the technical details of their approach to solve the challenge, demonstrate their results at a scheduled session, and answer questions raised at the session. The winner will be selected on the basis of the obtained results, the quality of the final presentation, and the capability to address questions.

Provided: Final test material comprising a selection of database excerpts and the Challenge Pieces selected by the three best teams.

Submitted: 1. Beat time output for the real-time embedded device for the final test material. 2. A revised report in the form of an IEEE conference paper describing the technical details of the real-time beat tracking implementation.

3. Formation of Competition Teams

Each team participating in the 2017 SP Cup is to be composed of one faculty member (as the supervisor), at most one graduate student (as a tutor), and at least three but no more than 10 undergraduate students. At least three of the undergraduate team members must hold either regular or student memberships of the IEEE Signal Processing Society. Undergraduate students who are in the first two years of their college studies as well as high school students who are capable to contribute are welcome to participate in a team. A participant should not be on more than one team.

4. Evaluation Criteria

Real-time operation is a fundamental requirement.

The total performance measure will be a weighted sum of three scores:

$$\text{Total Score} = (1/6) \times \text{Human Beat Time Annotations from Part 1} + (1/2) \times \text{Real-time embedded algorithm performance score} + (1/3) \times \text{Creative application score}$$

The scoring of the beat times for the real-time embedded algorithm performance score will be based on a MATLAB scoring function that provides an accuracy score based on Allowed Metrical Levels and the convergence time of the algorithm. The accuracy score is based on a comparison of estimated beat times with annotated ground truth. It calculates the proportion of continuously correct beat estimates occurring with perceptually specified tolerance windows around the ground truth annotations. To mirror the ambiguity in human perception of the beat in music, estimated beats at twice

or half the tempo of the ground truth annotations will also be considered correct.

Special certificates may be awarded at the discretion of the judging panel to best teams among the teams consisting of all student participants at the 2nd year of undergraduate study or younger.

5. Upload Submissions

Participating teams must submit their results for the open competition stage Part 1 by **November 7, 2016** and Part 2 by **December 21, 2016**.

Each submission should include:

Part 1

1. Three 30 second musical excerpts along with human annotated beat times.

Part 2

1. Software version (with instructions on how to run the software) of the real-time algorithm implemented on the embedded device.
2. The beat time output for the real-time embedded algorithm for the both the provided database and the participant submitted musical excerpts.
3. A video or link to an online video of the real-time beat tracking application in action for an easy and hard musical excerpt.
4. A report in the form of an IEEE conference paper describing the technical details of the real-time beat tracking application.

More details and guidelines about the submission process will become available through the SP Cup website.

6. Prize for Finalists

According to the guideline from the IEEE Signal Processing Society, a maximum of three members from each of the three finalist teams will receive travel support to attend ICASSP2017 for the final competition (up to \$1,200 for continental travel or \$1,700 for intercontinental travel per member, and at most three people from each team will be supported). The participants can claim their travel expenses on a reimbursement basis.

More team members are also welcome to attend. Although these additional members will not be provided with any travel grant, those members who will not be presenting a paper at the conference will be offered a complimentary ICASSP registration. The finalist teams will also be invited to join the Conference Banquet as well as the Student Career Luncheon, so that they can meet and talk to SPS leaders and global experts.

A Judging Panel will be set up to select the ultimate winners at the conference. The teams will present the technical details of their approach to solve the challenge, demonstrate their results at a scheduled session, and answer questions raised at the session. The winner will be selected on the basis of the obtained results, the quality of the final presentation, and the capability to address questions. The champion team will receive a grand prize of \$5,000. Combining the grand prize, travel grant, and complimentary conference registrations, the total value received by the championship team can be \$10,000+. The first and the second runner-up will receive a prize of \$2,500 and \$1,500, respectively, in addition to the above mentioned travel grants and complimentary conference registrations.

7. Important Dates

| | |
|-------------------|--|
| June 12, 2016 | Competition webpage and preliminary info are available. |
| June 30, 2016 | Data are available online. |
| November 7, 2016 | Deadline for Team Registration to join the competition and Phase 1 submission. |
| December 21, 2016 | Deadline for submitting open competition results for Phase 2. |
| January 10, 2016 | Announcement of best three teams. |
| March 5-9, 2017 | Final competition at ICASSP 2017 |

8. Online Resources

Main page of SP Cup on the SPS Website:

<http://www.signalprocessingsociety.org/community/sp-cup/>

For technical details of the competition project, please visit:

https://piazza.com/ieee_sps/other/sp1701/home

General information and resources are available on Piazza without requiring login; in order to access datasets and references as well as to participate in the discussions and Q&A, please visit this link:

https://piazza.com/ieee_sps/other/sp1701

to set up a free account and use the access code “spcup2017” to join as a student to “SP 1701: SP Cup 2017”.

9. Organising Team

The organization of 2017 SP Cup Competition is led by members of the IEEE Audio and Acoustics Signal Processing Technical Committee (AASP) in collaboration with colleagues.

Dan Ellis (Columbia University, USA)

Matthew Davies (INESC TEC, Porto, Portugal)

Dataset & Web Masters: Craig Jin and Matthew Davies

Liaison: Jessica Perry, Membership and Content Administrator, IEEE SPS.

“SP Cup” is overseen by the Student Service Committee of the IEEE Signal Processing Society (Patrizio Campisi, Chair).

10. Background

The material below has been taken directly from (permission obtained from authors) the following resources:

1. [This is Your Brain on Music](#) Book by **Daniel J. Levitin**, Dutton Publishers, 2006.
2. [Beat Tracking and Musical Metre Analysis](#) Chapter 4 by **Stephen Hainsworth** in [Signal Processing Methods for Music Transcription](#), editors **Anssi Klapuri** and **Manuel Davy**, Springer, 2006.
3. [Lecture Notes on Beat Tracking](#) by **Dan Ellis** from his class on Music Signal Processing.
4. Slides 35 to 63 from [Tutorial on Music Signal Processing](#) by **Mark Plumbley** and **Simon Dixon** presented at the IMA Conference on Mathematics in Signal Processing, December, 2012.
5. [Tempo and Beat Tracking: Extracting predominant local pulse information from musical recordings](#), **Meinard Müller**, *IEEE SPS Online Video Library*, September 13, 2014.

Each paragraph starts with the name(s) of the author(s) where the material is taken from.

What is Beat Tracking ?

Stephen Hainsworth: "Imagine you are sitting in a bar and your favourite song is played on the jukebox. It is quite possible that you might start tapping your foot in time to the music. This is the essence of beat tracking and it is a quite automatic and subconscious task for most humans. Unfortunately, the same is not true for computers; replicating this process algorithmically has been an active area of research for well over twenty years, with reasonable success achieved only recently."

Some Musical Definitions

Daniel Levitin: "**Rhythm** is what we dance to, sway our bodies to, and tap our feet to. ...it is the relationship between the length of one note and another. Among the most famous rhythms in our culture is the rhythm often called "shave-and-a haircut, two bits," sometimes uses as the "secret" knock on a door. ... Lyrics were attached to the rhythm in a song by Jimmie Monaco and Joe McCarthy called "Bum-Diddle-De-Um-Bum, That's It!". ... In the William

Tell overture by Rossini (what many of us know as the theme from The Lone Ranger) we also hear a series of notes of two different lengths, long and short: da-da-bump da-da-bump da-da-bump bump bump. The long notes are twice as long as the short ones and the rhythmic ratio of 2:1 appears to be a musical universal."

Daniel Levitin: "**Tempo** refers to the pace of a musical piece - how quickly or slowly it goes by. If you tap your foot or snap your fingers in time to a piece of music, the tempo of the piece will be directly related to how fast or slow you are tapping. If a song is a living, breathing entity, you might think of the tempo as its gait - the rate at which it walks by - or its pulse - the rate at which the heart of the song is beating." ... [Paula Abdul's "Straight Up"](#) and [AC/DC's "Back in Black"](#) have a tempo of 96, meaning that there are 96 beats per minute. In "Back in Black" you can hear the drummer playing a beat on his high-hat cymbal at the very beginning, steadily, deliberately, at precisely 96 beats per minute."

Daniel Levitin: "**Beat** indicates the basic unit of measurement in a musical piece; this is also called the *tactus*. Most often, this is the natural point at which you would tap your foot or clap your hands or snap your fingers. Sometimes, people tap at half or twice the beat, due to different neural processing mechanisms from one person to another as well as differences in musical background, experience, and interpretation of a piece. Even trained musicians can disagree on what the tapping rate should be. But they always agree on the underlying speed at which the piece is unfolding. ... Two songs can have the same tempo but feel very different. In "[Back in Black](#)," the drummer plays his cymbal twice for every beat (eighth notes) and the bass player plays a simple, syncopated rhythm perfectly in time with the guitar. On "[Straight Up](#)" there is so much going on, it is difficult to describe it in words. The drums play a complex, irregular pattern with beats as fast as sixteenth notes, but not continuously - the "air" between drum hits imparts a sound typical to funk and hip-hop music. The bass plays a similarly complex and syncopated melodic line that sometimes coincides with and sometimes fills in the holes of the drum part. In the right speaker (or the right ear of headphones) we hear the only instrument that actually plays on the beat every beat - a Latin instrument called an *afiche* or *cabasa* that sounds like sandpaper or beans shaking inside a gourd. Putting the most important rhythm on a light, high-pitched instrument is an innovative rhythmic technique that turns upside down the normal rhythmic conventions. While all this is going on, synthesizers, guitar, and special percussion effects fly in and out of the song dramatically, emphasizing certain beats now and again to add excitement. Because it is hard to predict or memorize where many of these are, the song holds a certain appeal over many, many listenings."

Daniel Levitin: "**Meter** refers to the way in which the pulses or beats are grouped together. Generally when we're tapping or clapping along with music, there are some beats that we feel more strongly than others. It feels as if the musicians play this beat louder and more heavily than the others. This louder, heavier beat is perceptually dominant, and other beats that follow it are

perceptually weaker until another strong one comes in. Every musical system that we know of has patterns of strong and weak beats. The most common pattern in Western music is for the strong beats to occur once every 4 beats: STRONG-weak-weak-weak STRONG-weak-weak-weak. Usually the third beat in a four-beat pattern is somewhat stronger than the second and fourth: There is a hierarchy of beat strengths, with the first being the strongest, the third being next, followed by the second and fourth. ... In "[Jailhouse Rock](#)," by Elvis Presley and written by two outstanding songwriters of the rock era, Jerry Leiber and Mike Stoller, the strong beat occurs on the first note Presley sings, and then every fourth note after that: "

- [Line 1:] WAR-den threw a party at the
- [Line 2:] COUN-ty jail (rest) the
- [Line 3:] PRIS-on band was there and they be-
- [Line 4:] GAN to wail

Daniel Levitin: "In music with lyrics, the words don't always line up perfectly with the downbeats; in "Jailhouse Rock" part of the word *began* starts before the strong beat and finishes on that strong beat. ... In "[That'll Be the Day](#)" by Buddy Holly, the strong beat occurs every fourth notes, just as in "Jailhouse Rock". The tactus is four beats between downbeats ... all caps indicate the downbeat as before, and **bold** indicates when you would tap your foot against the floor:"

- Well
- **THAT**'ll be the **day** (rest) when
- **YOU** say good-bye-yes;
- **THAT**'ll be the **day** (rest) when
- **YOU** make me cry-hi; you
- **SAY** you gonna leave (rest) you
- **KNOW** it's a lie 'cause
- **THAT**'ll be the **day**-ay-
- **AY** when I die

Daniel Levitin: Syncopation. "If you pay close attention to the song's lyrics and their relationship to the beat, you'll notice that a foot tap occurs in the middle of some of the beats. The first say on the second line actually begins before you put your foot down - your foot is probably up in the air when the word say starts, and you put your foot down in the middle of the word. The same thing happens with the word yes later in that line. Whenever a note anticipates a beat - that is, when a musician plays a note a bit earlier than the strict beat would call for - this is called syncopation. The syncopation catches us by surprise, and adds excitement."

Daniel Levitin: Backbeat. "When people clap their hands or snap their fingers with music, they sometimes quite naturally, and without training, keep time differently than they would do with their feet: They clap or snap not on the downbeat, but on the second beat and the fourth beat. This is the so-called backbeat that Chuck Berry sings about in his song "[Rock and Roll Music](#)." In "Rock and Roll Music," as with most songs, the backbeat is what the snare

drum is playing: The snare drum plays only on the second and fourth beat of each measure. ... In ["We Will Rock You"](#) by Queen, we hear what sounds like feet stamping on stadium bleachers twice in a row (boom-boom) and then hand-clapping (CLAP) in a repeating rhythm: boom-boom-CLAP, boom-boom-CLAP; the CLAP is the backbeat."

Computer Beat Tracking

Stephen Hainsworth: **Computer beat tracking** involves estimating the possibly time-varying tempo and the locations of each beat. In engineering terms, this is the frequency and phase of a time-varying signal, the phase of which is zero at a beat location (i.e., where one would tap one's foot). When musical audio signals are used as an input, the aim of 'beat-tracking' algorithms is to estimate a set of beat times from this audio which would match those given by a trained human musician.

Ellis and/or Plumbley&Dixon: **Overview of a Beat Tracking System** A beat-tracking system is typically comprised of a front-end system that extracts audio events (e.g., onsets) and a back-end system that sequences the beats. The front-end system generally consists of some form of onset detection.

Ellis and/or Plumbley&Dixon: **Onset Detection** There are many approaches to onset detection. Onset detection can be performed in the time domain or frequency domain and can use the signal amplitude or phase. The most common approach to onset detection determines some form of energy envelope of the signal and then finds maxima in this envelope. When the amplitude is unreliable, discontinuities in the phase can be used.

Müller: **Novelty Curve** The log-magnitude of the spectrogram can be used as a basis to compute pulses in the music. For example, the derivative across time of the spectrogram can be computed for each frequency and only the positive derivative values kept. The sum across frequency of these positive derivative values can then be computed to obtain a novelty curve. The novelty curve can be normalized by computing the local average and subtracting this local average from the original novelty curve.

Ellis and/or Plumbley&Dixon and/or Müller: **Tempo Induction** The back-end system is comprised of some combination of tempo induction and beat tracking. Tempo induction refers to finding the tempo of a section of music and beat tracking refers to finding the times of each beat at some metrical level. Tempo induction clearly relies on finding periodicities in the audio signal. Common features use for periodicity detection are: onset time, amplitude, pitch, percussive events, energy in frequency bands, energy variations, spectral features, etc. There are many methods to determine periodicity and some are briefly described here:

- **Autocorrelation:** Autocorrelation measures the self-similarity of a signal with itself at varying time lags. For example, if $E(n)$ is an energy envelope of the signal, we have:

$$r(\tau) = \sum_{n=0}^{N-\tau-1} E(n)E(n+\tau)$$

- **Oscillating filter:** A bank of filters which oscillate maximally at different resonant frequencies are exposed to the signal and the filter with the maximum response is picked for the tempo. Beat location is then identified by calculating the phase of the oscillating signal that is output from the filter. A comb filter with delay τ can be used:

$$y_{\tau}(t) = \alpha_{\tau} y_{\tau}(t - \tau) + (1 - \alpha_{\tau}) x(t)$$

where α_{τ} is the gain, $\alpha_{\tau} = 0.5^{\tau/t_o}$, and t_o is the half-time.

- **Histogramming:** Histogramming is similar to the autocorrelation approach. With histogramming, we look at the time interval between successive onsets or the time interval between onsets that are further apart. We can bin these time intervals and create a histogram. The maximum of the histogram indicates the tempo.
- **Predominant Local Pulse:** The tempo can be analysed using a frequency domain approach. For example, windowed sinusoids of various frequencies can be correlated with each frame (e.g., a 4s window) of the normalized novelty curve. The windowed sinusoids with maximum correlation can then be kept for each frame and accumulated across time using an overlap-add method. This accumulated signal of windowed sinusoids can be half-wave rectified to obtain a predominant local pulse signal indicating the tempo.

Ellis and/or Plumbley&Dixon: Beat Tracking The back-end system performs beat tracking after the tempo induction. The main issue is to make the best selection of beat times given the tempo. A common approach is to have an explicit, underlying model specified for the rhythm process and then to adjust the parameters of this model using probabilistic methods such as a Kalman filter, particle filtering, and hidden Markov models. An elegant example of one approach to beat tracking is to apply dynamic programming to optimize the beat times based on a cost function that combines onset strength and tempo consistency (see the Matlab Example section in **Getting Started** below).

11. Getting Started

Suggestions are made below on how to get started.

Reading:

1. Pages: **55 to 80** and **165 to 171** of [This is Your Brain on Music](#) Book by **Daniel J. Levitin**, Dutton Publishers, 2006.
2. Pages: **101 to 129** in [Beat Tracking and Musical Metre Analysis](#) Chapter 4 by **Stephen Hainsworth** in [Signal Processing Methods for Music Transcription](#), editors **Anssi Klapuri** and **Manuel Davy**, Springer, 2006.
3. [Tempo and beat analysis of acoustic musical signals](#), **Eric D. Scheirer**, *Journal of the Acoustical Society of America*, **103**(1), 558-601, 1998.
4. [Lecture Notes on Beat Tracking](#) by **Dan Ellis** from his class on Music Signal Processing.
5. [Beat tracking by dynamic programming](#), **Dan Ellis**, *Journal of New Music Research*, **36**(1), 51-60, 2007.
6. Slides **35 to 63** from [Tutorial on Music Signal Processing](#) by **Mark Plumbley** and **Simon Dixon** presented at the IMA Conference on Mathematics in Signal Processing, December, 2012.
7. [Evaluation of the audio beat tracking system BeatRoot](#), **Simon Dixon**, *Journal of New Music Research*, **36**(1), 39-50, 2007.

8. [Extracting predominant local pulse information from music recordings](#), **Peter Grosche** and **Meinard Müller**, *PIEEE Transactions on Audio, Speech, and Language Processing*, **19**(6), 1688-1701, 2011.
9. **Meinard Müller**. Tempo and beat tracking. In [Fundamentals of Music Processing](#), chapter 6, pages 303-354. Springer Verlag, 2015.

Video Tutorial:

1. [Tempo and Beat Tracking: Extracting predominant local pulse information from musical recordings](#) **Meinard Müller**, *IEEE SPS Online Video Library*, September 13, 2014.

Beat Annotation:

1. Download [Sonic Visualiser](#) software.
2. Watch [tutorial videos](#) on using Sonic Visualiser.
3. **Matthew Davies: Music Tapping:** Open Sonic Visualiser. Download [tap_example1.wav](#), Goto *File, Open*, browse to directory, and select "tap_example1.wav", click *Open*. Goto *Layer* and then *Add new time instants layer*. Locate the ';' (semi-colon) key on the keyboard. Press the space bar to start audio playback. Tap the beats to the music using the ';' key. Listen to the taps by pressing the space-bar again to restart playback. Goto *File, Export Annotation Layer*. Browse to directory. Choose "Files of type".txt. Click *Save*. Try again using [tap_example2.wav](#).

MATLAB Example:

Visit [Dan Ellis's page on beat tracking](#). Try out the code found on the page. You will find that you need [fft2melmx.m](#) which is part of the [labROSA Cover Song Identification](#) code. Also visit, the [Tempogram Toolbox page](#), developed by Peter Grosche and Meinard Müller, which contains code for general functions on tempo and pulse tracking - useful for "playing around."

Sonic Visualiser Examples:

Visit the [VAMP Plugins page](#) for Sonic Visualiser. Download and install the *BeatRoot* and *INESC Porto Beat Tracker* plugins. Test the plugins using Sonic Visualiser (click on *Transform* and then on *Analysis by Plugin Name*).

Creative Transformations and Beat Tracking:

Visit [Matthew Davies's page on beat tracking](#). Try out the **beat workshop** that can be found on the page!